CLAWAR 2017: 20th International Conference on Climbing and
Walking Robots and the Support Technologies for Mobile Machines,
Porto, Portugal, 11-13 September 2017.

GECO: THE DEVELOPMENT OF A WALL-CLIMBING ROBOT

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This paper describes the process of designing a reliable wall-climbing robot that can be produced easily. We found that designers can choose out of many possible technologies to make wall climbing robots. After exploration and prototyping with gecko tape, suction caps, microsplines, magnetism, impellers and propellers we came up with GECO. GECO is a wall climbing robot which uses suction to move across walls. GECO moves over different kinds of surfaces, is wireless controlled and relatively easy to build. We envision that wall-climbing robots have potential applications for example to inspect surfaces, clean and maintain buildings and many more.

Keywords: wall-climbing, robotics, design process

1. Introduction

Robotics is a disrupting market that impacts global industries and changes our lives for the better. Digital production techniques are also flourishing and opening new possibilities for makers in the world of DIY (Do-It-Yourself). The goal of our research is to overcome the threshold of the maker for making wall climbing robots. With this requirement in mind, the robot has to be digitally producible, reliable and it should be easy to apply the knowledge to different concepts.

Over the last decades wall-climbing robots have been build by researchers and companies (see[1] for a good overview). Examples vary from robots with a tracked wheel mechanism[2] to gecko-like robots, such as Stickybot developed at Stanford University.[3] The robot is made with gecko-tape and can only move across surfaces as long as they are smooth and clean. NASA has created wall-climbing robots using microsplines[4] which work well for climbing on rough surfaces. Moreover, together with Disney, ETH Zurich developed a super-fast wall climbing robot using propellers. Unfortunately, this example remains undocumented and thus making it complex for the DIY community to build. Another approach is to use impellers which turn out to be very reliable such as the City-Climber developed at City University of New York.[5,6]

The present paper reports that we build four prototypes of wall-climbing robots based on gecko's, impellers, slapping mechanisms and tracked wheels. All four prototypes were evaluated on feasibility as well reliability and mobility. After this evaluation, the most promising prototype (the impeller robot) was selected for further development. This paper documents both, the prototyping process as well the details of the impeller robot GECO.

The remainder of this paper is structured as follows. In Section 2 we discuss the technical details of our four wall-climbing prototypes. Next, the four prototypes are evaluated in Section 3. Finally, in Section 4 we highlight our conclusions.

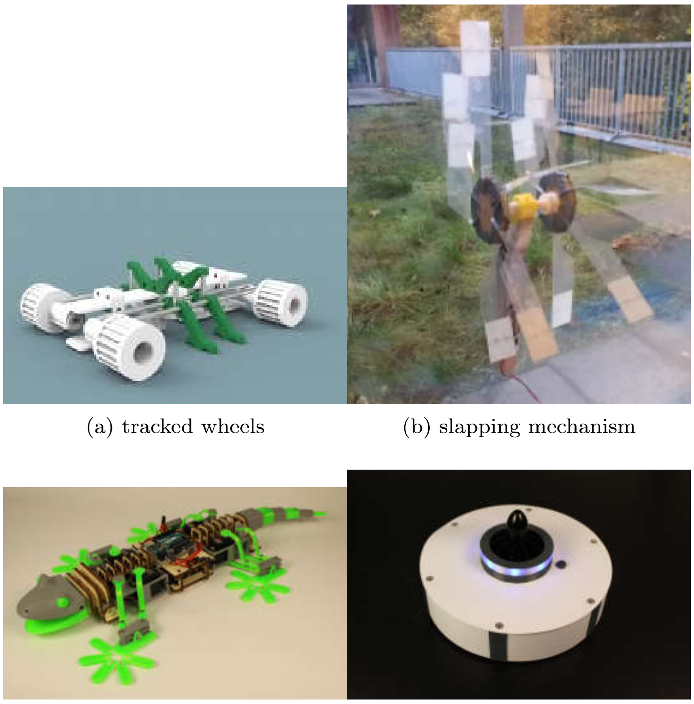
2. Four wall-climbing prototypes

2.1. *Tracked wheels*

The prototype, see Figure 1(a), consists of a body made with a 3D printer (Polyactide - PLA), 2 DC-motors which controls the tracked wheels, and batteries. It can be turned on and off with a simple switch. The tracked wheels are fully covered with gecko tape. A smart system is built in to push the tracked wheels against the surface allowing the gecko tape to make better contact. The prototype can only move forward with a constant speed.

2.2. *Slapping mechanism*

Figure 1(b) shows us the result of our prototype with a slapping mechanism. It is made out of cardboard and has 2 DC-motors built in which control the wheels with 6 flaps. These are driven by batteries, which can be turned on and off with a simple switch. We stick some gecko tape on the tips of each flap. When the wheels are turning, the flaps that are touching the



(a) tracked wheels (b) slapping mechanism

(c) bioinspired walking mechanism (d) impeller robot

Figure 1. Four wall-climbing robot mechanisms

surface, will peel off, and some other flaps will slap against the surface. This process repeats itself 6 times (once per flap) in one rotation of a wheel. The prototype is limited to forward motion.

2.3. *Bioinspired walking*

The design of this robot is based on the morphology of a real gecko. While the previous prototypes were not very promising with respect to reliability for wall climbing, prototypes of our bioinspired walking robot indicated that wall climbing should be possible. For this reason, we developed multiple prototypes of this robot of which the final prototype is illustrated in Figure 1(c). The robot is 61 cm long, 38,5 cm wide and 6,7 cm high. The total weight of the robot is 861 g. It is fully made with digital production techniques (laser cutting (low weight multiplex) and 3D printing (PLA)). The main parts of the robot are the torso, the legs, the head and the tail.

The legs were designed based on real gecko legs. One leg consists of 3D printed parts, two servo motors, two springs and some screws and nuts to connect everything. The total weight of one leg is 145 grams. We can distinguish 3 different parts of the leg: (1) a shoulder (gray part in Figure 2 of the middle panel), (2) an arm (green part in Figure 2 of the middle panel) and (3) a foot (red part in Figure 2 of the middle panel).

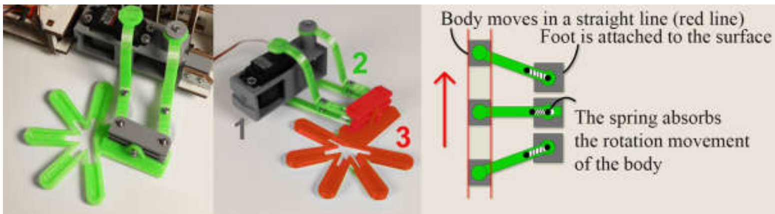


Figure 2. Detailed pictures of the legs.

The first servo controls the shoulder of the robot, which drives the up and down movement. The second servo controls the arm of the robot, which drives the forward and backward movement. In the arm, 2 incisions are made with a length of 10 mm to make sure the foot can move freely. The two springs push the foot away from the body. When the foot is attached to a surface (with gecko tape) and the body moves relative to the foot (the robot walks forwards or backwards), the springs are pushed inwards and absorb the circular movement of the servos. When the leg is lifted (and doesn't touch the surface anymore), the springs push the foot away from the body, putting it back in its starting position. This is illustrated in the right panel of Figure 2.

The electronics used in the robot are the servo motors and some transistors. These are controlled by an Arduino and powered with a lithium-polymer battery. Due to the strict time constraints, we were able to build in the electronics, but we have not been able to fully test the robot on a wall.

2.4. *Impeller robot*

The fourth prototype consisted of an impeller robot. Just as with the bioinspired robot, the robot design went through multiple prototypes. The final result is given in Figure 1(d).

In order to keep the weight of the robot limited, we made the base of the robot with 4 mm poplar wood and the cover of 0,5 mm Polypropylene.

Both materials are lasercutted to get the best accuracy and finishing. The other parts of the robot (electronics excluded) are 3D printed (PLA). The robot has a diameter of 25 cm and a height of 5,5 cm. The total weight of the robot is 878 g.

The core of the robot is an Arduino which controls a motor board for the wheels, an electronic speed controller system for the impeller and a Wi-Fi module. A lithium-polymer battery (2600 mAh) powers the robot. The Wi-Fi module makes it possible to connect to the robot from a tablet or computer. On the top of the robot, there is an on/off button and a LED-strip attached that gives visual indications of the status (e.g., red light if the battery is running low) to the user.

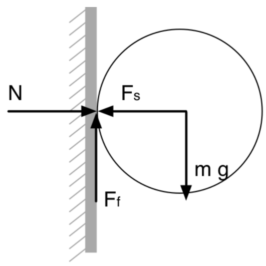


Figure 3. Schematic overview of the static forces

By calculations we determined the impeller specifications for our robot. Figure 3 gives a schematic overview of the static forces. F_{s} represents the force needed from the impeller (the thrust), N is the normal force of the surface, F_{f} is the friction force of the surface and mg is the impact of the weight. The friction F_{f} can be derived by: $mg = 2F_{\mathrm{f}}$ (with $m = 0.878$kg and g the gravity constant).

With F_{f}, we can calculate the normal force N on each wheel. We use the coefficient of friction μ from the material used for the wheels (rubber on concrete: $mu = 0.6$): $F_{\mathrm{f}} = \mu N$. From N we can derive the required suction force (the thrust): $F_{\mathrm{s}} = 2N$. The suction force is twice the normal force because because there are two wheels that create friction.

3. Evaluating wall-climbing robots

All prototypes were first evaluated on feasibility. When passing this criterium, we took more criteria into account including: easy to deploy, reliability and mobility.

3.1. *Tracked robot*

The idea behind this robot is rather simple: attach gecko tape (a commercially available brand) to the tracks and let it drive on the wall. However the robot has a huge difficulty with sticking on the wall while driving. When the robot starts moving upwards, the pressure of the tracks against the wall decreases. When this pressure is too low to carry the weight, the robot falls down. A smart system was therefore placed in the middle of each track, that should push the tracks against the surface to create a better adhesion of the gecko tape. This pushing system failed because of some wrong choices in the dimensions of the design. After these experiments we stopped prototyping this mechanism.

3.2. *Slapping mechanism*

A lot of different options were tested to achieve a working prototype. The principle however was always the same (a cardboard model with 1 or 2 DC motors). We added more flaps to the wheels to have more gecko tape touching the surface and added some batteries to increase the power of the motor. Nevertheless, nothing resulted in a wall climbing robot. The motor starts working, but after one full rotation the tape loses its grip on the surface and falls down.

3.3. *Bioinspired walking*

We started by testing the capabilities of the gecko tape. We tested how much weight the tape could carry and on which surfaces the gecko tape works best. Out of these results we could conclude that this technology was feasible (2 cm^2 could carry 2 kg in optimal conditions) and easy to deploy but has restrictions in mobility (it only works on smooth and clean surfaces).

The next step was making one leg using a SG-90 servo motor. After some iterations we found a prototype that could attach and detach the leg to and from the surface. This was a very promising result.

In the second phase of the design process, a 4 legged robot was made. With this prototype, 2 servos are used per leg to give the legs an extra DOF. This prototype taught us a lot. The final robot had to be lighter, stronger and the center of mass had to be closer to the surface.

The issues we have experienced with the first prototypes are taken into account for the last model. We documented the final prototype on instructables*. Due to time limitations of the project we were not able to perform any tests. The impeller robot had more promising results, so we focused on making this our working robot.

3.4. *Impeller robot*

In the first phase of prototyping, we tested if a simple model made of cardboard could stick to a wall. These first tests were negative. A small remark: we used a propeller (used in quad-copters), with a corresponding DC motor; this is not an ideal situation. We searched for new solutions (other dimensions, small and large adjustments with duct tape, changing the gap between the propeller and surface, etc.). With these adjustments and by calculating the weight and forces, we managed to get the result we were hoping for.

The next step was to make this robot mobile. We thought of a propulsion system which made use of the airflow from the impeller. Unfortunately, this idea failed. After this we placed some wheels on the bottom of the robot and powered them with the DC motors. Moving upwards did not work yet, but we already had some promising results when moving downwards.

With these conclusions, the final prototype was made (described earlier in this paper in the system description of the impeller robot). This final robot† got new and stronger motors for the wheels so the robot was able to move in all directions and was designed with lighter and stronger materials. With these improvements, we finally achieved an impeller robot that could move freely on a wall in all directions. Up to this moment we tested our GECO with success for climbing smooth surfaces such as concrete, glass, wood and gyproc walls.

4. Conclusions

Making a wall-climbing robot is not easy. Especially when time and budget are restricted. We have faced a lot of struggles and difficulties and had to make a lot of prototypes before finally achieving a working model. We learned that extensive testing with robots is very difficult with quick and dirty prototypes. Our design process resulted in a wall climbing impeller

*See `https://www.instructables.com/id/Bioinspired-Wall-Climbing-Robot-Without-Electronic/` for how-to-make instructions

†See `https://www.instructables.com/id/GECO-Wall-Climbing-Robot/` for how-to-make instructions

robot GECO. GECO is fully open source (instructions can be found online) and is designed to make sure everyone could (re)build it with digital production techniques.

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